University of Ljubljana, Faculty of Computer and Information Science
Doctoral study programme Computer and Information Science

Elective courses BDR-RI 2026/2027

All courses are 5 ECTS. There are two types of courses available.

The **lecture** type courses are delivered as regular lectures and follow the format 15-20-15 (lectures-seminar-tutorial hours).

The **individual research** type courses introduce advanced technological breakthroughs or practical solutions in computer and information science. Students work under the lecturer's supervision on a seminar topic related to the student's doctoral research topic. Each course can be selected by at most six students. The course lecturer can be the advisor or co-advisor of the student selecting the course. Each student can take at most three individual research courses.

Lecture type courses offered in 2026/2027:

Advanced Topics in Sustainable Computing

(Selected Topics in Computer Systems 1, Miha Mraz)
Lecturer: Veljko Pejović, Mojca Ciglarič
Course code: 63830D
Course type: lectures, spring (second) semester

The course critically examines computing systems within the context of planetary ecological limits, resource constraints, and broader societal sustainability challenges. The course treats sustainability not only as a technical optimisation problem, but as a socio-technical issue that spans computer science, environmental science, economics, policy, and human-computer interaction. Students will investigate the environmental impacts of ICT infrastructures across their lifecycle, including operational and embodied emissions, material extraction, e-waste, and the growing energy and water demands of datacentres, networking infrastructure, edge computing, and IoT systems. The course introduces students to critical assessment of rebound effects (through an innovative teaching method), technocentrism, and the sustainability implications of continued growth in computational demand. In addition to examining the sustainability of ICT itself, the course explores how computing can support broader sustainability transitions through lifecycle analysis, optimisation, and sustainability-oriented design. Topics include automated LCA analysis with large language models, sustainable HCI, sustainability by design, frugal computing, and sustainability standards and certifications. A semestre-long research project forms the core of the course, requiring students to conduct an original investigation into a sustainable computing problem (ideally tied with their PhD research area) and present their findings through presentations and a final report.

Large Language Models: Machine Learning View

(Selected Topics in Artificial Intelligence 1, Zoran Bosnić)
Lecturers: Marko Robnik Šikonja
Course code: 63834D
Course type: lectures, fall (first) semester

The course presents large language models (LLMs) from the point of view of machine learning, covering the main ideas used in their creation, adaptation, and application. In this context, it presents advanced machine learning topics used in representation learning, including topics from ensemble learning, explainable artificial intelligence, transfer learning, and graph learning. The contents commonly apply in natural language processing, natural language understanding, knowledge graphs, multi-relational learning, digital humanities, bioinformatics, etc. The specific technical contents of the course cover neural network architectures for large language models, relevant large language model adaptions and extensions, retrieval augmented generation, and multimodal models. The course requires students to apply large language models, typically to language and graph processing tasks, preferably in the context of their research work.

Machine Learning and Artificial Intelligence

(Selected Topics in Artificial Intelligence 1, Zoran Bosnić)
Lecturers: Blaž Zupan
Course code: 63834E
Course type: lectures, fall (first) semester

This course is an introduction to data science for non-computer scientists. The course covers topics from data preparation, clustering, regression and classification, model evaluation, and embedding of unstructured data.

Restrictions/Prerequisites: The course will be promoted by the University's Doctoral School, and we expect enrollment from students of engineering, natural sciences, and humanities. ***The course is not intended for computer science students or students whose curricula already included courses on machine learning or data science.*** *No prior knowledge on the topics is assumed. This course will not use computer programming and no prior knowledge on statistics or data science is required.*

Tensor Networks for Machine Learning

(Selected Topics in Artificial Intelligence 2, Zoran Bosnić)
Lecturers: Bojan Žunkovič
Course code: 63835E
Course type: lectures, fall (first) semester

Tensor networks are decompositions of multi-dimensional tensors with an exponential reduction in the number of parameters. They were introduced to quantum mechanics roughly 25 years ago and have since become one of the central technical tools for understanding the structure of quantum states — especially in one dimension — and a key ingredient of state-of-the-art numerical techniques in many-body quantum mechanics. Tensor networks are now a well-established and well-understood tool with known geometric properties and robust optimization algorithms. In the past fifteen years they have also appeared in the mathematical literature, in particular as matrix product states (tensor trains) applied to linear algebra with very large matrices. Over the past decade, they have increasingly appeared in the machine-learning literature, where they have been applied to a range of practical problems — from parameter compression and classification to positive–unlabeled learning, privacy-preserving inference, generative modelling, and more recently as a unifying viewpoint on linear recurrent / state-space models such as RetNet and Mamba. Theoretically, tensor networks are related to Born machines, hidden Markov models, probabilistic automata, and quadratic automata. The course focuses on recent tensor-network applications for machine learning, primarily from an experimental/numerical perspective, and connects them to the emerging field of quantum machine learning.

Chatbots for Researchers

(Selected Topics in Artificial Intelligence 2, Zoran Bosnić)
Lecturer: Blaž Zupan
Course code: 63835F
Course type: lectures, fall (first) semester

This course is an introduction to ChatGPT and similar large language models. It will cover an introduction with intuitive explanation of what are large language models. We will continue with use cases of ChatGPT's web-based interface, focusing on how it can assist researchers in various tasks, including providing instant access to a vast range of information, facilitating brainstorming, generating ideas, and summarizing complex concepts. It can also assist in reviewing and editing research documents, proposing research questions, and helping researchers understand complex methodologies and techniques in various disciplines. We will discuss the deficiencies of the technology, including the provision of inaccurate or outdated information and lack of

understanding or context awareness, reflecting limitations in its training data and the absence of real-world experience or subjective perception. The course will showcase the use of ChatGPT's application programming interface (API) and its advanced uses, including AutoGPT.

Restrictions/Prerequisites: The course will be promoted by the University's Doctoral School, and we expect enrollment from students of engineering, natural sciences, and humanities. The course is not intended for computer science students or students whose curricula already included courses on machine learning or data science. No prior knowledge on the topics of large language models or computer programming is assumed. This is an introductory course intended for general audience. Students from humanities, social sciences, natural sciences and engineering are welcome.

AI & Cybersecurity

(Selected Topics in Artificial Intelligence 2, Zoran Bosnić)
Lecturer: Areeb Ahmed
Course code: 63835L
Course type: lectures, fall (first) semester

This doctoral-level course explores the intersection of artificial intelligence and cybersecurity from a research-driven and system-oriented perspective. It addresses both the use of AI for cybersecurity (e.g., detection, automation, and threat intelligence) and the security of AI systems themselves (e.g., adversarial attacks, robustness, and resilience). Building upon foundational concepts introduced in earlier study cycles, the course advances toward state-of-the-art research topics, including adversarial machine learning, secure AI architectures, trustworthy AI, and emerging threats in AI-integrated systems. The course is designed to:

- develop a deep conceptual understanding of AI security challenges,
- enable critical analysis of contemporary research literature, and
- support students in formulating novel research ideas relevant to their doctoral work.

Individual research type courses offered in 2026/27

Qualitative Research Methods in Computer and Information Science

(Selected Topics in Informatics 2, Denis Trček)
Lecturer: Damjan Fujs
Course code: 63827
Course type: individual research course, spring (second) semester

The field of computer and information science has traditionally emphasized quantitative research methods. This course introduces a novel perspective by exposing doctoral students to alternative research approaches, specifically the application of qualitative methods. By integrating these methods, students can gain deeper and complementary insights to enrich their predominantly quantitative research. This course introduces doctoral students to key concepts, approaches, and techniques in qualitative research, with a focus on their application within computer and information science. Students will gain an understanding of the research underpinnings of qualitative inquiry, explore common data collection and analysis methods, and critically assess their use in empirical research. The course encourages reflection on ethical considerations, the researcher's role, and the value of qualitative approaches in addressing complex questions in socio-technical environments. Through independent and guided work, students will be supported in developing research designs aligned with qualitative traditions, applicable to their own doctoral projects or problem domains. The idea is for students to use a qualitative method as a supplement to their primary research method, for example, using a focus group, interview, case study, observation, quasi-experiment, experiment, Delphi method, action research, grounded theory, etc.

Selected Topics in Analysis of Sound Signals

(Selected Topics in Software Development 1, Matija Marolt)
Lecturer: Matija Marolt
Course code: 63832
Course type: individual research course, fall (first) semester

Students will have the opportunity to explore the use of different methods for pattern recognition and machining learning (for example, deep neural networks) to solve the problems that we encounter when analyzing sound signals, such as identification of events in sound recordings, classification of sound recordings, transcription of music, detection of samples in music, etc. In the course of the semester, students will develop their own algorithm for solving a problem and send it to one of the evaluation campaigns (e.g., Mirex or DCASE), where its performance can be compared with approaches developed by other researchers (mostly PhD students) around the world.

Selected Topics from Computer Graphics and Visualization

(Selected Topics in Software Development 1, Matija Marolt)
Lecturer: Ciril Bohak
Course code: 63832B
Course type: individual research course, fall (first) semester

Students will learn the current methods and technologies in the field of three-dimensional computer graphics. Emphasis will be given to rendering different types of data: volumetric data, point clouds, mesh geometry, and logically defined geometry in the fields of medicine, biology, geodesy, and high-energy physics. Because the rendered data can be very large, emphasis will also be given to applying appropriate algorithms and data structures for fast and real-time rendering, implementation of techniques on graphic processors, and remote rendering. The students will get to know the benefits of modern graphics libraries (Vulkan, WebGPU) for addressing these challenges. In addition to the techniques, the students will also get acquainted with the different ways of visualizing such data, how to utilize various deep learning tools on the data for visualization preparation or visual parameter estimation, and how to select suitable visualization methods for an individual domain. Students will have an opportunity to collaborate and interact with other students and staff from one of the world's best Visual computing groups in the world at KAUST.

Edge AI

(Selected Topics in Software Development 2, Matija Marolt)
Lecturer: Vlado Stankovski and Petar Kochovski
Course code: 63833
Course type: individual research course, spring (second) semester

In the duration of this course, selected chapters will be presented and analyzed across the domains of the Internet of Things, Artificial Intelligence, Cloud-to-Things computing, semantic technologies, Digital Twins, and blockchain technologies. By incorporating human-centric approaches to software development, probabilistic mechanisms to tackle bias in decision-making, decentralized identities, and secure, trustworthy data management, the course aims to foster novel, smart, and reliable services and applications. The course will cover the following areas:

1. Foundational concepts, vision and goals of cloud, fog and edge computing with respect to security, trust and service reliability.
2. Cognitive and context aware computing, and bias mitigation in artificial intelligence. probabilistic decision-making techniques for addressing bias in algorithms, human-in-the-loop methodologies for transparent and fair AI.
3. Decentralized democratic governance mechanisms, consensus-based proofs, verification and certification for the Next Generation Trusted Internet supporting humanity in all aspects of life.
4. Advanced concepts related to scalability, interoperability, energy efficiency, privacy and security. Designing the building blocks of the Next Generation Internet and dependable frameworks and infrastructure for global connectivity.
5. Advanced concepts of ontologies, resource models, reputation and tokenization mechanisms for decentralised information and knowledge management.
6. Advanced concepts of Digital Twins, Secure, trustworthy handling of real-time data streams, ensuring integrity and reliability across distributed systems.

Advanced Topics in AI for Medicine

(Selected Topics in Artificial Intelligence 1, Zoran Bosnić)
Lecturer: Zoran Bosnić
Course code: 63834F
Course type: individual research course, fall (first) semester

This course will offer an exploration of the integration of artificial intelligence (AI) and machine learning (ML) methodologies in healthcare and medicine. Through individual research work, students will have an opportunity to address topics, examining the use of AI in medical diagnosis, treatment, and patient management. Specifically, students will investigate the application of deep learning techniques in analyzing medical imaging data, the development of predictive models for personalized treatment strategies, and the utilization of natural language processing algorithms for extracting valuable insights from clinical text repositories. The examples of such AI applications include existing applications in cardiology, focusing on the development of predictive models for early detection of cardiac diseases and risk stratification of patients; and applications in the intersection of AI and neurodegenerative diseases, particularly Parkinson's and Alzheimer's, investigating the potential of AI-driven approaches in early detection and disease progression monitoring through analysis of biomarkers, neuroimaging data, and patient records. The goal of the course would be to enable PhD students develop their research skills in an actual and particular research areas, while also meaningfully contributing to the ongoing advancement of this interdisciplinary field.

Restrictions/Prerequisites: A good foundation in machine learning and programming. Beneficial is a basic understanding of concepts and healthcare systems. Maximum number of students: 6.

In-Depth Computer Vision Research

(Selected Topics in Artificial Intelligence 2, Zoran Bosnić)
Lecturer: Matej Kristan
Course code: 63835G
Course type: individual research course, spring (second) semester

The course will focus on a selected topic in computer vision that connects to the candidate's doctoral thesis. The main aim of the course is to expand the research with intensive training on how to tease out the most relevant related works in computer vision, analytically or experimentally discover their drawbacks, make original contributions, and validate them. Computer vision involves the development of algorithms that can abstract complex unstructured data, such as images and videos, in a broad sense. This encompasses tasks like semantic segmentation, visual object tracking, object detection, extraction of 3D information, visual data generation, and their application to various downstream tasks like image/video manipulation and mobile robotics. The student will begin by selecting a suitable topic within their broader tentative doctoral research area, with the guidance of their supervisor. A specific goal, achievable within a single semester (approximately 150 hours of work), will be defined. The student will then establish a research plan and provide progress reports through bi-weekly meetings. The initial reports will involve breaking down and critically analyzing existing works closely related to the chosen topic from a methodological perspective. A series of test-and-hypothesis-generation sessions will be conducted, challenging the student to identify a localized big-picture idea that can lead to a scientific contribution in their selected area. This intensive training aims to equip the student with a robust methodology for approaching scientific discovery within computer vision and encourage them to generate their contributions. The ultimate objective is a high-caliber scientific contribution meeting publication quality standards necessary at a prominent computer vision venue. Moreover, the student will develop the ability to critically review relevant papers on arXiv as part of their daily routines (expected to spend an hour a day), ensuring they stay updated with daily scientific advancements. A secondary outcome of the course is to foster an understanding of the

characteristics that distinguish top publications. The student will gain the knowledge and skills to reproduce the style and rigor required for high-quality scientific reporting in computer vision.
Restrictions/Prerequisites: The course is primarily aimed at doctoral candidates who have started their doctoral training under the mentorship of the course lecturer. The students' doctoral topic must be from the core computer vision topic. The appropriateness of the topic will be judged by the lecturer, and the candidate is invited to consult the lecturer before applying for the course.

Machine Learning for Remote Sensing

(Selected Topics in Artificial Intelligence 2, Zoran Bosnić)
Lecturer: Luka Čehovin Zajc
Course code: 63835K
Course type: individual research course, spring (second) semester

The course will combine two very complementary topics. On the one hand, we have machine learning, a methodological framework for building prediction models based on statistics of data. On the other hand, we have remote sensing, a prime example of which is Earth observation using a growing number of satellites. These satellites produce enormous quantities of sensory data that can only be analyzed using computers. Through individual research projects, the course will explore the opportunities and challenges of using machine learning methods on remote sensing data.

Advanced image-based biometrics

(Selected Topics in Artificial Intelligence 2, Zoran Bosnić)
Lecturer: Peter Peer
Course code: 63835H
Course type: individual research course, spring (second) semester

With the advances of computer vision with deep learning biometrics gained a lot of extra traction. This is evident from the papers published in the top-notch conferences like CVPR, ICCV, ECCV, FG, IJCB, journals like PAMI, TIFS, TIP, IVC, KBS, and also in a number of competitions organised each year. The research conducted in the field of biometrics improves security and privacy issues in society - two of very relevant questions that even the general public is very interested in. Based on the student doctoral topic, we will link it to selected biometrical modality to address open research questions, for instance, in: segmentation and recognition models, bias assessment, generation of synthetic datasets, privacy-preserving biometrics, deidentification, input quality assessment and enhancement, deepfake detection.
Restrictions/Prerequisites: Familiarity with the basic computer vision and deep learning approaches. Maximum number of students: 3.